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Computer-based tools are designed and implemented to improve the quality and speed of the analysis of results from large scale optimization models. These tools are needed to manage the voluminous output generated by these models. This approach is applied to the United States Air Force model HEAVY ATTACK which is a large-scale non-linear optimization program used to plan air-to-ground munitions requirements. A single execution of the model produces about 4,500 lines of results. The HEAVY ATTACK decision-making process is studied and specific analysis tools are designed and implemented with a spreadsheet program on a personal computer.

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Analysis Tools for United States Air Force
Sortie Optimization and Munitions Planning

by

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requirements for the degree of

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ABSTRACT

Computer-based tools are designed and implemented to improve the quality and speed of the analysis of results from large scale optimization models. These tools are needed to manage the voluminous output generated by these models. This approach is applied to the United States Air Force model HEAVY ATTACK which is a large-scale non-linear optimization program used to plan air-to-ground munitions requirements. A single execution of the model produces about 4,500 lines of results. The HEAVY ATTACK decision-making process is studied and specific analysis tools are designed and implemented with a spreadsheet program on a personal computer.

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I. INTRODUCTION

Over the past several years, the computational power of mainframes and personal computers has increased manyfold. Much larger and more complex optimization models (involving multiple scenarios) can be solved in less time. This implies a commensurate growth in the size of output. The sheer volume of output from these models is overwhelming; multiple-run comparisons involve even more output. Current analysis techniques have become awkward and time consuming.

Given sufficient time, detailed output analysis for almost any model can be accomplished. However, decision makers usually place time restrictions upon the analyst. The scope of analysis usually must be narrowed down to some manageable size. The application of automated analysis tools offers the potential to do more thorough analysis in less time.

Computer tools are necessary to automate the analysis process and manage the vast amount of data and output. The aim of these tools is to enhance the analysis process by improving the quality, speed and scope of output analysis, and reduce data input errors. The design of visualization tools to aid operations research analysis must be preceded by a careful evaluation of the decision-making process. Applicable visualization principles [Ref. 1:p. 11-12] must be incorporated into the design. There are many different ways to present information, therefore, design choices must be made.

The focus of this thesis is to (1) analyze a decision-making process and identify analysis choke points, (2) design analysis tools, and (3) demonstrate them.

An important operations research model, HEAVY ATTACK, has been selected to demonstrate these tools. This large-scale optimization model has been used by the Combat Forces Division at Headquarters, United States Air Force, for over two decades to generate air-to-ground munitions requirements for the Air Force Statement of Requirement in order to justify procurement objectives. HEAVY ATTACK is widely accepted by the Department of Defense and the Congress, and is used to help plan the expenditure of over $2 billion each year. Recently, HEAVY ATTACK was used by the Combat Forces Division for analysis of munitions requirements for Operation Desert Storm.

Chapter II provides a general view of the HEAVY ATTACK model. Chapter III describes the current difficulties with using HEAVY ATTACK and with analyzing its output. Steps to improve the analysis are described. Chapter IV discusses the implementation of the analysis tools. These tools are based on spreadsheets. Chapter V states the conclusions.

II. HEAVY ATTACK MODEL

For over 25 years mathematical programming has been the foundation for the budget planning of air-to-ground conventional ordnance by the Combat Forces Division within the Directorate of Operations of the United States Air Force. The planning goal is to ensure sufficient quantities of war reserve munitions are purchased annually. The Division's Air-to-Ground Nonnuclear Consumables Annual Analysis (A/G NCAA) (Figure 2-1) currently uses three programs — SELECTOR, HEAVY ATTACK, and HEAVY GOAL — to accomplish this goal. These models reside on a mainframe computer in the Pentagon.

A. A/G NCAA METHODOLOGY

In the annual analysis process the first model, SELECTOR, determines weapons effectiveness based on the Joint Munitions Effectiveness Manual (JMEM) [e.g. Ref. 2], weather, aircraft attrition and cost. The JMEM lists the average number of targets of type j killed by sortie type i using a specified tactic t in a given weather of type w. SELECTOR takes the JMEM data and produces, as an input to HEAVY ATTACK, the average number of targets of type j killed by sortie type i [Ref. 3:p. 4]. The data is then sorted from the most cost-effective to the least. Because the most effective weapon is usually the most expensive or because there may be a high attrition rate to the aircraft when employing a specific tactic, SELECTOR chooses the most cost-effective tactic.

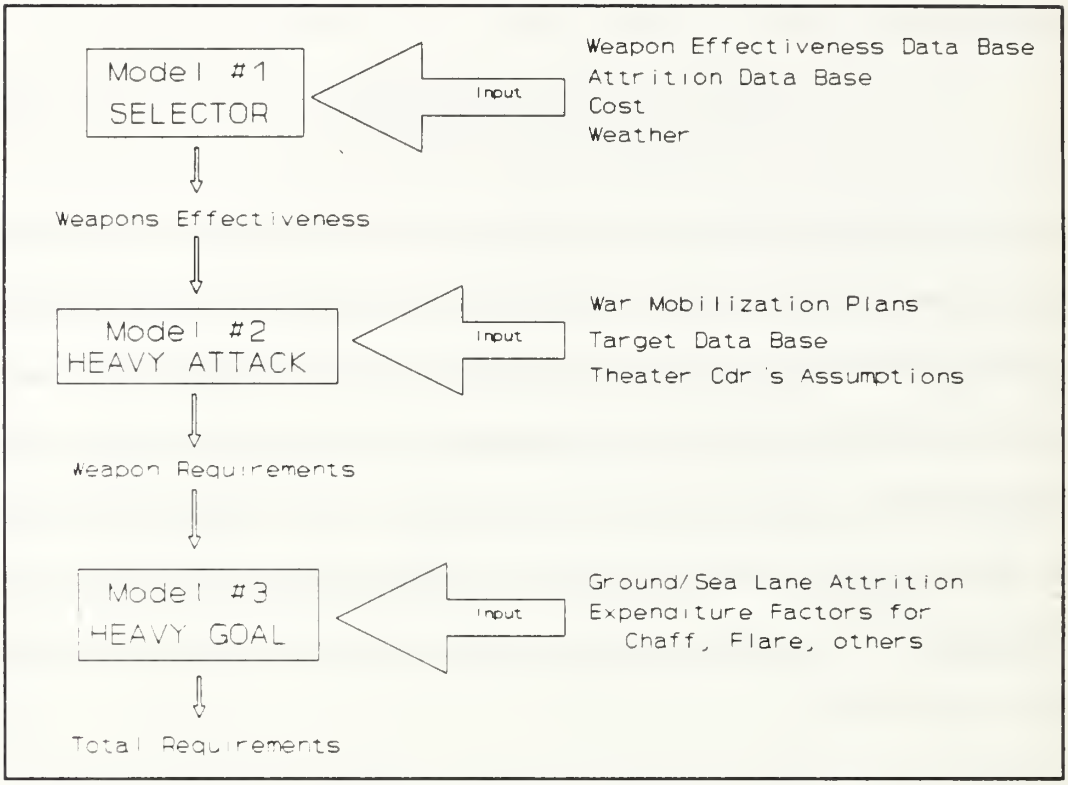

Figure 2-1. A/G NCAA Methodology Overview.

The second program, HEAVY ATTACK, is the cornerstone of the planning effort. It is a FORTRAN-based, large-scale optimization program with a nonlinear objective function and linear constraints. For each of seven time periods, varying in duration from hours to months, HEAVY ATTACK uses the SELECTOR-nominated optimum weapon for each aircraft/target combination, loads that weapon onto the aircraft, and allocates aircraft sorties to each target. The model's objective is to maximize the expected value of targets destroyed taking into account, among other things, aircraft attrition, the ability of targets to regenerate themselves, weather, and Von Clausewitz's "fog of war" [Ref. 4]. In essence, HEAVY ATTACK fights a multi-period, theater-level war to determine the requirements for ordnance stock.

The Combat Forces Division operates these models and, for each respective major Air Force theater, hosts an individual annual week-long air-to-ground NCAA planning conference at the Pentagon. Senior staff officers bring their commander's theater plan for their conference. This HEAVY ATTACK input is what the commander assesses is his mission, the threat he is facing, the enemy's order of battle, and his war fighting strategy. Other data input requirements for HEAVY ATTACK include the sortie effectiveness data, weather, aircraft availability and weapon inventory. Aircraft availability, provided by the Combat Forces Division, is obtained from the Air Force War and Mobilization Plan, which allocates tactical air forces between the theaters. Weapon inventories are apportioned among the theaters by the Combat Forces Division. [Ref. 5] HEAVY ATTACK takes these inputs and produces the weapon requirements for each theater.

When each theater has completed its annual visit, their requirements are combined to form an input to the last model — HEAVY GOAL. HEAVY GOAL takes the combined requirement, plus attrition rates for sea lift and in-theater ground transportation, and furnishes the aggregate weapon requirements for the Air Force Program Objective Memorandum (POM).

B. HEAVY ATTACK OPTIMIZER

In 1974 the Air Force adopted a nonlinear programming model written by Clasen, Graves, and Lu from RAND Corporation to "select an air-to-surface munitions mix to be stockpiled as war reserve inventory." [Ref. 6:p. 1] The objective was to maximize the "military worth" of targets destroyed by allocating sorties to targets. Their single period munitions mix methodology consisted of three steps: (1) selecting a munition

for each aircraft-target combination based on a criterion of least-cost-per-expected-target-killed; (2) allocating aircraft sorties to targets, with each sortie carrying the selected "optimum" munition; and (3) computing the required munitions mix. Figure 2-2 shows the relationship between these steps and various inputs.

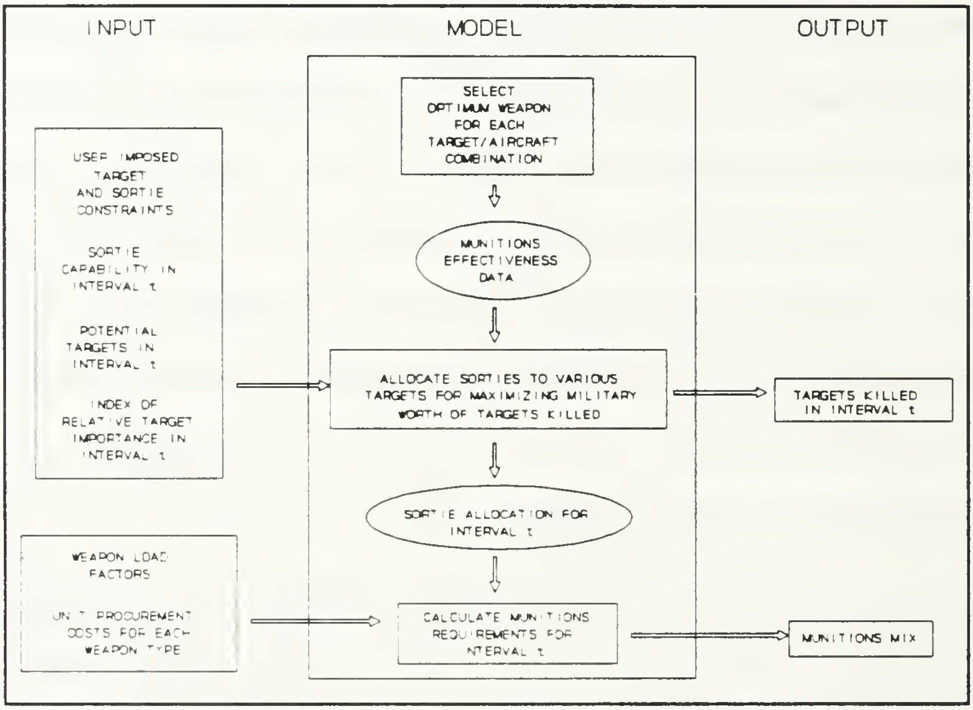

Figure 2-2. HEAVY ATTACK Optimization Process. [Ref. 5:p. 2]

C. INPUTS TO HEAVY ATTACK

There are many sources of data for HEAVY ATTACK for each theater. The commander's theater plan provided to the Combat Forces Division is one major input; it is in the form of the Target Data File described below.

Another input, the weather distribution, plays an important role in how HEAVY ATTACK allocates aircraft to targets. The distribution forecasts meteorological conditions for the theater in the form of prior probabilities for six discrete weather bands ranging from foul to clear weather.

Aircraft availability and weapons inventory constitute the remaining major inputs and are provided to the theater teams by the Combat Forces Division.

Nine input files are required for HEAVY ATTACK. These files are classified as data, exclusion, or other. Currently, all files reside on a Pentagon mainframe computer. They are modified using the mainframe's text editor. The data and exclusion files, which represent the majority of the data, are described in detail below. Since the "other" files are easily updated with the mainframe editor, they are neither included in the analysis, nor described.

1. Data Files

Targets, aircraft and weapons are defined in base data files.

a. *Target Data File*

The target file (Figure 2-3) is the commander's theater plan. There have been as many as 85 different target types.

1992 NPS, UNCLASSIFIED					TARGET VALUES						REGENER			
TGT	QTY	TE	V1	V2	V3	V4	V5	V6	V7	CC	DAYS	QTY	F/M	
1(00000)TG01	16.	2	14.0	12.0	8.0	8.0	8.0	8.0	8.0	.20	5.	17.		TARGET 01
2(00000)TG02	8.	1	10.0	10.0	10.0	10.0	10.0	10.0	10.0	.50	2.	8.		TARGET 02
3(00000)TG03	324.	1	1.0	5.0	15.0	15.0	15.0	15.0	12.0	.50	2.	16.		TARGET 03
4(00000)TG04	162.	1	1.0	5.0	15.0	15.0	15.0	15.0	13.0	.50	2.	16.		TARGET 04
5(00000)TG05	10.	1	5.0	5.0	10.0	10.0	10.0	10.0	10.0	.20	10.	0.		TARGET 05
•						•								•
•						•								•
85(00000)TG85	1180.	3	2.0	2.0	1.0	1.0	1.0	1.0	1.0	.30	2.	28.		TARGET 85

Figure 2-3. Example of an unclassified HEAVY ATTACK Target Data File. The United States Air Force provided these numbers from an unclassified data set. The heavy dots indicate a continuation of data.

(1) Target Name and Description. The name may be up to four characters and the description up to 15. Two examples are 'ABHU — AC Bkr, Hrd,Ugnd' (Hardened, Underground Aircraft Bunker) and 'SA9 — SA-9 SAM battery' (a Soviet-made surface-to-air missile (SAM) battery).

(2) Quantity. The number of targets within each target type.

(3) Target Element. The number of elements of a target type. For example, each of the 40 tank parks (quantity of targets) may contain five tanks (target elements).

(4) Time Weighted Target Value. A value given to each target type for each of the seven time periods. This value indicates how important it is to the commander to kill a target type relative to all other types for a given time period. For example, a SAM battery would be weighted high in the first two to three periods and low in the remaining. Because SAM's are a very high threat to aircraft, it makes sense to destroy them at the beginning of the war in order to achieve air superiority, hence the high initial value. On the other hand, destroying a logistics target at the beginning of the war does not make military sense; therefore, they have a low initial value and are higher in the last few time periods.

(5) Coefficient of Confirmability. This number, between zero and one, symbolizes the ability of a pilot to assess his battle damage to the target. The coefficient mathematically expresses Clausewitz's "fog of war" principle. If pilots cannot confirm kills, or discriminate between live targets and destroyed targets, they will waste attacks and munitions on already destroyed targets. The number one indicates a pilot is unable to confirm the effect of his first weapons delivery, while zero represents perfect target damage assessment [Ref. 7:p. 14].

(6) Regeneration Days and Quantity. These specify the average number of days required to regenerate a destroyed target type and the number of replacements the enemy has. Regeneration is the process by which destroyed targets are replaced with available spares (a pontoon bridge for a destroyed spanning bridge)

or repaired (filling in the bomb craters on a runway). Additional information may be found in [Ref. 8:p. 14].

b. Aircraft Data File

This file (Figure 2-4) contains the aircraft allocated to the theater by the Air Force War and Mobilization Plan. There have been as many as 25 different types of aircraft.

```
  SEL# SAB# ATT#  WX#   TEST   SPECIAL CAPABILITY      OMC          ARC
     1    1    0    2   AC1A                             0            0
     2    2    0    2   AC2                              0            0
     3    5    0    1   AC5A                             0            0
     •                   •                                            •
     •                   •                                            •
    13    1    0    2   AC1B                             0            0
     0
   .05  .20  .22  .14  .08  .31
 --AC1--- --AC2--- --AC5A-- --AC5B-- --AC8--- --AC6--- AC3A/B/C -AC3D/E- --AC4---
 A/C#   AIRCRAFT          PER1    PER2    PER3    PER4    PER5    PER6    PER7
   1    AC1A               888    1221    1008    1747    1366    1272       0
        1                 0.92    0.92    0.92    0.92    0.92    0.92    0.00
   2    AC2                331     391     309     510     360     337       0
        2                 0.92    0.92    0.92    0.92    0.92    0.92    0.00
   3    AC5A               205     255     368     630     525     516       0
        3                 0.92    0.92    0.92    0.92    0.92    0.92    0.00
        •                                  •                                 •
        •                                  •                                 •
  13    AC1B               222     305     252     437     342     318       0
        1                 0.95    0.95    0.95    0.95    0.95    0.95    0.00
```

Figure 2-4. Example of an unclassified HEAVY ATTACK Aircraft Data File.

(1) Selector Number. The SELECTOR file index of this aircraft type.

(2) Weather Number. The number one indicates the aircraft is all-weather radar delivery capable.

(3) Aircraft Name. Up to four characters, e.g. F15C, A10A.

(4) Category Label. Each aircraft type is placed into one of nine available categories for the output reports. Examples are FALCON and EAGLE. This aggregation is used by HEAVY GOAL to identify collateral support requirements.

(5) Aircraft Category Number. This identifies the category of each aircraft.

(6) Number of Sorties. Identifies the total number of sorties each aircraft type is capable of flying for each time period.

(7) Attack Mission Percentage. The percentage of sorties devoted solely to air-to-ground attack missions for each time period.

c. *Weapon Data File*

All theaters use the same weapon data base; there have been as many as 65 weapon types (See Figure 2-5). For planning purposes the allocation of weapons among the theaters is decided by the Combat Forces Division.

WPN#	IDENT	DESCRIPTION	P/NP	WPN COST	MAX EXPEND
1	WP01	WEAPON 1	0	0	7710.
2	WP02	WEAPON 2	0	0	547.
3	WP03	WEAPON 3	0	0	41284.
4	WP04	WEAPON 4	0	0	0.
5	WP05	WEAPON 5	0	0	5002.
	•		•		•
	•		•		•
65	WP65	WEAPON 65	0	0	270.

Figure 2-5. Example of an unclassified HEAVY ATTACK Weapon Data File.

(1) Weapon Number. A numeric index.

(2) Weapon Name and Description. The name may be up to four characters and the description up to 25. An example is LGB — Laser Guided Bomb.

(3) Play/No Play. This is a binary switch (zero, one). The number one removes the weapon from HEAVY ATTACK.

(4) Maximum Expenditure. States the inventory allocated to the theater.

2. Exclusion Files

Not every aircraft/target/weapon combination is desirable or feasible in a sortie plan. Some convenient method is necessary to exclude particular combinations. Of the possible combinations, HEAVY ATTACK accepts inadmissable lists of aircraft versus targets, aircraft versus weapons, and aircraft/targets versus weapons. These exclusion files are used to preclude combinations which are not militarily feasible.

The data in each exclusion file is in pairs of rows. For example, in the Aircraft versus Target Exclusion File shown in Figure 2-6, the first row in each pair is the aircraft type. The following row contains the target types which **will never be attacked** by its paired aircraft type.

```
 1
  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
 1
26 27 28 29 38 40 41 45 47 51 56 57 59 60 61 62 63 64 66 67 69 71 72 73 74
 1
75 76 77 78 79 81 85
 2
  1  2  3  4  5  6  7  8 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
 •
 •
13
 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
13
26 27 28 29 38 40 45 47 56 59 60 61 62 63 64 66 67 68 69 70 71 72 73 74 75
13
76 77 78 79 80 81 82 83 84 85
```

Figure 2-6. Example of a HEAVY ATTACK Aircraft versus Target Exclusion File. Length for the unclassified data set is 48 lines.

The Aircraft versus Weapon Exclusion File is similar, except the numbers on the following row of each pair are the weapon types which **will never be expended** by its corresponding aircraft type.

The remaining exclusion file is the Aircraft/Target versus Weapon Exclusion File shown in Figure 2-7. Here, the first row of each pair contains the aircraft type followed by the target type. The following row is the weapon types which **will never be expended by that aircraft against that target.**

```
1, 5
2  4  6  8  9 10 11 12 14 15 17 20 23 24 25 34 42 46 53 55
1, 5
57 58
1,12
2  4  6  8  9 10 11 12 14 15 17 20 23 24 25 26 27 34 38 46
1,12
47 51 53 55 57 58
•
•
99,85
1  2  3  4  5  6  7  8  9 10 11 12 14 15 18 19 23 24 42 46
99,85
47 55 57 58
```

Figure 2-7. Example of a HEAVY ATTACK Aircraft/Target versus Weapon Exclusion File. Length for the unclassified data set is 244 lines.

D. OUTPUT FROM HEAVY ATTACK

HEAVY ATTACK produces three reports: short, medium, and long. The Combat Forces Division analyst mainly uses the short report (Figure 2-8). It is divided into two sections: results for each time period and then cumulative results through all seven periods. In the first section, data concerning weapons expended by aircraft category and target types destroyed are listed for each time period. The second contains the same data as the first, accumulated through the time periods, plus the distribution of weapon types to target types. The final data table listed in the report is the cumulative and maximum allowable expenditure of weapons used during the "war".

The medium report is also divided into two sections: results for each time period and cumulative results. The first section lists the expected kills of targets by aircraft,

WEAPON	TOTAL	END OF PERIOD 1						
TYPE	EXPENDED	-CAT A--	-CAT B--	-CAT C--	-CAT D--	-CAT E--	-CAT F--	-CAT G--
WP01	1874	1316	0	0	0	0	0	0
WP03	362	362	0	0	0	0	0	0
WP04	5402	1871	0	923	345	0	2162	99
WP07	882	0	882	0	0	0	0	0
•				•				•
•				•				•
WP38	164	0	0	0	0	110	0	53

TARGET RECONSTITUTION AND RESUPPLY, END OF PERIOD 1

TARGET TYPE	STARTING TARGETS	PRIOR TARGETS	NEW TARGETS	FRAC FIXED	TARGETS FIXED	CUM FIXED	NEWLY KILLED	CUM KILLED	RESULT TARGETS
1 TG01	16.	16.	0.	0.451	0.	0.	16.	16.	0.
2 TG02	8.	8.	0.	0.777	0.	0.	0.	0.	8.
3 TG03	324.	324.	0.	0.777	0.	0.	0.	0.	324.
4 TG04	162.	162.	0.	0.777	0.	0.	0.	0.	162.
•				•					•
•				•					•
85 TG85	0.	0.	0.	1.000	0.	0.	0.	0.	0.

TARGET	TOTAL SORTIES	TARGETS KILLED	PERCENT KILLED	POT KILL	POT VALUE
TG01	40	16.00	100	16.0	224.0
TG08	138	10.36	49	10.9	272.6
TG16	206	20.65	94	22.0	550.0
TG18	221	42.00	100	42.0	840.0
•					•
•					•
TG79	21	24.00	100	24.0	360.0

TARGET/WEAPON SUMMARY FOR TIME PERIOD(S) 1- 1

TARGET	WP01	WP02	WP03	WP04	WP05	WP06	WP07	WP08	WP09	WP10	WP11	WP12
TG08	558	0	0	0	0	0	0	0	0	0	0	0
TG18	0	0	0	0	0	0	882	0	0	0	0	0
TG19	0	0	0	0	0	0	0	0	0	419	980	0
TG22	0	0	0	4527	0	0	0	0	0	0	0	0
•						•						•
•						•						•
TG79	56	0	0	0	0	0	0	0	0	0	0	0

WEAPON TYPE	CUMULATIVE EXPENDITURE	MAXIMUM EXPENDITURE
WP01	7710	7710
WP02	0	547
WP03	41284	41284
WP04	23551	9999999
•		•
•		•
WP38	270	270

Figure 2-8. Example of a HEAVY ATTACK Short Report. Length for the unclassified data set is 1500 lines.

the allocation of aircraft sorties to targets, and the expenditure of weapons by aircraft. The second part accumulates the same aircraft allocation and weapons expenditure data (see Figure 2-9).

```
   WEATHER DISTRIBUTIONS  1  0.05     2  0.20     3  0.22     4  0.14     5  0.08     6  0.31
                          1  0.00     2  0.21     3  0.23     4  0.15     5  0.08     6  0.33
-----------------------------------------------------------------------------------------------
****** AGGREGATE EXPECTED KILLS PER SORTIE ******

*********** WEATHER CONDITIONS INCLUDED **********
              AC01   AC02   AC03   AC04   AC05   AC06   AC07   AC08   AC09   AC10       AC13
 1  TG01     0.127  0.193  0.000  0.242  0.442  0.242  0.000  0.000  0.144  0.302      0.127
 2  TG02     0.000  0.000  0.000  0.000  0.175  0.000  0.000  0.000  0.000  0.000      0.000
 3  TG03     0.000  0.118  0.000  0.000  0.518  0.000  0.169  0.169  0.000  0.000      0.000
 4  TG04     0.000  0.000  0.000  0.000  0.408  0.000  0.000  0.000  0.000  0.000 ••  0.000
    •                                            •                                      •
    •                                            •                                      •
85  TG85     0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000      0.000
-----------------------------------------------------------------------------------------------
   ALLOCATION OF SORTIES TO TARGETS
                                                   AIRCRAFT TYPES
TGT-(VAL)     AC01   AC02   AC03   AC04   AC05   AC06   AC07   AC08   AC09   AC10       AC13
               817    305    189    169    150    380    356    330      0    138 ••    211
TG01(14.00)      0      0      0      0     40      0      0      0      0      0          0
TG02(10.00)
TG03( 1.00)
TG04( 1.00)    110      0     21      0      0      0      0      0      0      0          0
   •                                              •                                        •
   •                                              •                                  ••    •
TG85(10.00)
ACFT SORTIES   817    305    189    169    150    380    356    330      0    138        211
TGTS KILLED    267     51     34     68     74     68     23     53      0     10         52
-----------------------------------------------------------------------------------------------
              EXPENDITURE PER SORTIE

 WPN TYPES                   AIRCRAFT TYPES
              AC01   AC02   AC03   AC04   AC05   AC06   AC07   AC08   AC09   AC10       AC13
   WP01      1.444  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  3.557      0.149
   WP03      0.400  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000      0.029
   WP04      0.793  0.000  4.501  1.875  0.000  5.004  0.001  0.249  0.000  0.000 ••   5.258
   WP07      0.000  2.665  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000      0.000
    •                                            •                                       •
    •                                            •                                       •
   WP38      0.000  0.000  0.000  0.000  0.694  0.000  0.003  0.131  0.000  0.000      0.000
```

Figure 2-9. Example of a HEAVY ATTACK Medium Report. Length for the unclassified data set is 2700 lines.

The long report, typically over 25,000 lines, contains all the information of the short and medium reports, plus additional information produced by the optimizer. Some additional information is evaluated by the analyst and the theater team, but the majority of the information is useful only in diagnosing any data errors identified by the optimization.

III. HEAVY ATTACK DECISION-MAKING PROCESS

Analysis of HEAVY ATTACK results is a tedious process. HEAVY ATTACK generates a tremendous amount of output. Because there is only one week for the planning conference the theater team scarcely has time for a thorough and in-depth analysis. In addition, multiple runs of HEAVY ATTACK are required in order to generate acceptable results, further exacerbating the problem.

A. STEPS TOWARD A SOLUTION

Three steps are employed — analyze the decision-making process, design analysis tools, and demonstrate them. The first step examines how the theater teams and current Combat Forces Division analyst and operator of HEAVY ATTACK, MAJ Lance Buckingham, USAF, make their decisions. Analysis choke points are identified. Second, a design is proposed to improve the time and quality of analysis. Finally, this design proposal is demonstrated with prototypic computer-based tools. A scenario will serve to illustrate the design.

B. THE DECISION-MAKING PROCESS

Figure 3-1 shows the HEAVY ATTACK decision-making process. When a theater team arrives at the Pentagon for their planning conference, the first step in the decision-making process is to create the HEAVY ATTACK input files. These files are manually reviewed for correctness. The Best Munitions Table Generator program is used to assist in reviewing the exclusion files. Errors in the exclusion files are

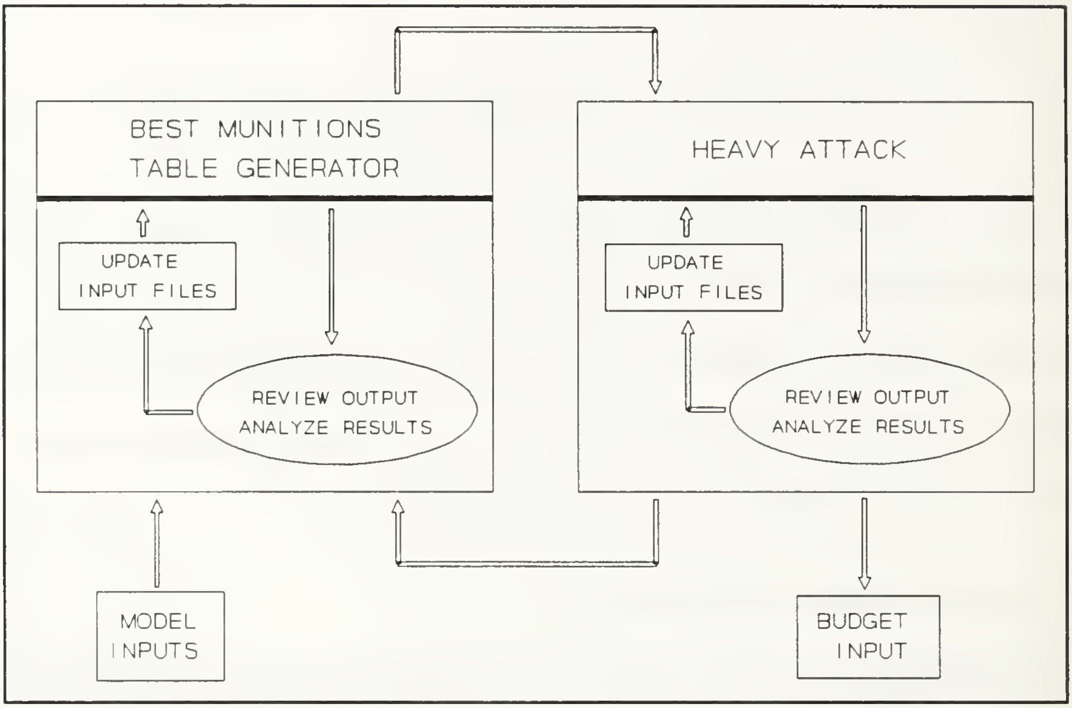

Figure 3-2. NCAA Decision-Making Process

corrected, and the Generator program is re-run. This cycle continues until the files appear error-free.

All input files are then passed to HEAVY ATTACK, and the model is run. The Combat Forces Division analyst evaluates the output to validate the model. The analyst will then present the model's results to the team, who will decide if any adjustments need to be made to the input files. The files are updated and the model is re-run. This cycle continues until the team achieves their final results. The team may also, during this cycle, send the updated exclusion files back into the Table Generator program to re-validate the tables. When the team is satisfied with the results from HEAVY ATTACK, their weapon requirements are combined with requirements from the other theaters an an input into HEAVY GOAL.

Two major analysis problems, or choke points, impede decision-making. First is the Table Generator program, which takes significant time to run and to evaluate. The second is the actual analysis of HEAVY ATTACK. Each of these choke points is amenable to automated analysis tools.

IV. ANALYSIS TOOLS FOR HEAVY ATTACK

In order to see how to improve the analysis of HEAVY ATTACK, one must understand how the analyst/theater teams presently use the model. Figure 4-1 is a current HEAVY ATTACK Aircraft Data File. There is an obvious problem: this file

```
 SEL# SAB# ATT#  WX#   TEST    SPECIAL CAPABILITY       OMC           ARC
    1    1    0    2   AC1A                               0             0
    2    2    0    2   AC2                                0             0
    3    5    0    1   AC5A                               0             0
    •                  •                                                •
    •                  •                                                •
   13    1    0    2   AC1B                               0             0
    0
  .05  .20  .22  .14  .08  .31
--AC1--- --AC2--- --AC5A-- --AC5B-- --AC8--- --AC6--- AC3A/B/C -AC3D/E- --AC4---
A/C#  AIRCRAFT            PER1     PER2     PER3     PER4     PER5     PER6     PER7
  1   AC1A                 888     1221     1008     1747     1366     1272        0
      1                   0.92     0.92     0.92     0.92     0.92     0.92     0.00
  2   AC2                  331      391      309      510      360      337        0
      2                   0.92     0.92     0.92     0.92     0.92     0.92     0.00
  3   AC5A                 205      255      368      630      525      516        0
      3                   0.92     0.92     0.92     0.92     0.92     0.92     0.00
      •                                       •                                   •
      •                                       •                                   •
 13   AC1B                 222      305      252      437      342      318        0
      1                   0.95     0.95     0.95     0.95     0.95     0.95     0.00
```

Figure 4-1. HEAVY ATTACK Aircraft Data File.

contains a lot of numbers with very little associated context. Because HEAVY ATTACK is a FORTRAN program, its output may be influenced by a single mis-aligned input field. The Target and Weapon Data Files (Figures 2-4 and 2-5) also exhibit this weakness.

The exclusion files also present major problems. Figure 4-2 is a restatement of the Aircraft/Target versus Weapon Exclusion File. As represented by the figure, these files are all numbers with no associated context. For example, the first and second lines of Figure 4-2 exclude aircraft type 1 from attacking target type 5 with weapon

```
 1, 5
 2  4   6   8   9 10 11 12 14 15 17 20 23 24 25 34 42 46 53 55
 1, 5
57 58
 1,12
 2  4   6   8   9 10 11 12 14 15 17 20 23 24 25 26 27 34 38 46
 1,12
47 51 53 55 57 58
 •
 •
99,85
 1  2   3   4   5   6   7   8   9 10 11 12 14 15 18 19 23 24 42 46
99,85
47 55 57 58
```

Figure 4-2. Example of an unclassified HEAVY ATTACK Aircraft/Target versus Weapon Exclusion File.

types 2, 4, 6, and so on. The exclusion files are the major source of errors with the input. Because of the difficulty in identifying errors in these files, the Table Generator program was created.

After HEAVY ATTACK is run, the output reports are generated. Figure 2-8 is just a portion of an unclassified Short Report, which contains information for each of the seven time periods plus accumulation across the seven periods. The week-long planning conference provides little time to thoroughly analyze the HEAVY ATTACK reports.

A. ANALYSIS IMPROVEMENTS

The next step was to design a computer system which might provide analysis improvements. Several commercially available programs were reviewed and Borland International's Quattro Pro 3.0 spreadsheet program was chosen. Quattro Pro provides superior graphic capabilities [Ref. 9,10,11,12] and "prints" to text (ASCII) files. This text file capability is extremely important in order to transfer data back and forth between desktop computers (Quattro Pro) and mainframes (HEAVY ATTACK).

Further, Quattro Pro provides the ability to import a text file and parse the information into usable spreadsheet cells.

The Quattro Pro-based analysis tool has been named QuikDraw. It is divided into two sections: Data Entry and Output Listing.

1. Data Entry

The Data Entry handles the data inputs for HEAVY ATTACK — specifically, the data and exclusion files described in Chapter II. The remaining "other" files are updated by the Combat Forces Division analyst using the mainframe computer's text editor. The HEAVY ATTACK Target and Weapon Data Files are combined into a single Quattro Pro worksheet. The Aircraft Data File has its own Quattro Pro worksheet (Figure 4-3). (The term worksheet is synonymous herein with file).

Currently HEAVY ATTACK lists combinations of aircraft, targets, and weapons which are militarily infeasible or invalid. However, the theater teams tend to think in terms of **valid** combinations. Therefore, QuikDraw has, for each HEAVY ATTACK exclusion file, a corresponding **inclusion** worksheet. Now, the users indicate with X's the valid combinations in the worksheets. Figure 4-4 shows the unclassified Aircraft versus Target Inclusion Worksheet.

The Best Munitions Table Generator program, which is the first choke point, is replaced by the inclusion worksheets. Hence, there is no need to execute the Generator program and analyze the generated tables.

AC #	Name	Use ?	SAB #	WEAX #	A/C CAT	PERIOD 1 MSNS	PERIOD 1 PCT	PERIOD 2 MSNS	PERIOD 2 PCT	PERIOD 3 MSNS	PERIOD 3 PCT	PERIOD 4 MSNS	PERIOD 4 PCT		PERIOD 7 MSNS	PERIOD 7 PCT
1	AC1A	Y	1	2	1	888	0.92	1221	0.92	1008	0.92	1747	0.92		0	0.00
2	AC2	Y	2	2	2	331	0.92	391	0.92	309	0.92	510	0.92	•••	0	0.00
3	AC5A	Y	5	1	3	205	0.92	255	0.92	368	0.92	630	0.92		0	0.00
	•															•
	•															•
25	----															

AIRCRAFT
CATEGORIES

1 --AC1A--
2 --AC2---
•
•
9 --AC4---

EXPECTED WEATHER BAND DISTRIBUTION

0.05	0.20	0.22	0.14	0.08	0.31
worst					best

Aircraft # : Just a numbering of aircraft from 1 to 25
Name: Limited to 4 characters
Use ?: Tells HEAVY ATTACK whether to consider this aircraft type
SAB # : Index to the SELECTOR file
WEAX # : 1—Indicates all-weather radar delivery capable. 2-Something less
Cat: Indicates which category the aircraft belongs to for output purposes
Missions: The total number of missions. This includes attack and air-to-air
Percent: The percent of total missions solely devoted to air-to-ground attack
Category: A label which aggregates aircraft for the different HEAVY ATTACK reports
Weather Band: The probability distribution of weather across 6 bands

Figure 4-3. Example of an unclassified QuikDraw Aircraft Data Worksheet.

X's represent VALID Aircraft/Target combinations

Use the DELETE key, not the SPACEBAR, to erase entries

		TG01	TG02	TG03	TG04	TG05	TG06	TG07	TG08	TG09	TG10	TG11	TG12		TG85
1	AC1A												X		X
2	AC2									X					X
3	AC5A	X	X				X	X	X	X		X	X		
4	AC5B	X	X	X	X	X	X	X	X	X	X	X	X		X
5	AC8	X	X	X	X	X		X	X	X	X	X	X		
6	AC6	X	X	X	X	X	X	X	X	X	X	X			
7	AC3A	X	X	X	X	X	X	X	X	X		X		•••	X
8	AC3B	X	X	X	X	X	X	X	X	X		X			
9	AC3C									X			X		
10	AC3D	X	X	X	X	X	X	X	X	X	X	X			X
11	AC3E	X	X	X	X	X	X	X	X	X		X	X		
12	AC4														
13	AC1B												X		
14	----														
15	----														
	•														
	•														
25	----														

Figure 4-4. Example of an unclassified QuikDraw Aircraft versus Target Worksheet.

After a user makes changes to any Data Entry worksheet and is ready to re-run HEAVY ATTACK, he executes a Quattro Pro macro program embedded in that worksheet. That macro will write the worksheet data to a text file. (For simplicity, the macro is executed with the same keystroke in each worksheet). Then, a FORTRAN program is executed to convert the text files into the format required for HEAVY ATTACK. This is necessary because HEAVY ATTACK, as a FORTRAN program, requires its input data to be in specific columns.

2. Output Listing

The Output Listing section has four worksheets; they are listed in Table I. Within each worksheet are three graph types: single run, multiple run, and cumulative. The single run graphs display information for the current run; multiple graphs present information from two successive runs. The cumulative graphs display "course of the war" information. All graphs display percentages, with raw numbers available below the graphs.

Table I. QUIKDRAW OUTPUT WORKSHEETS. THESE WORKSHEETS ARE CAPABLE OF GENERATING THREE TYPES OF GRAPHS. EXAMPLES OF THESE GRAPH TYPES ARE SHOWN IN FIGURES 4-5 THROUGH 4-8.

Aircraft Attack Missions Flown by Time Period
Weapon Types Expended by Time Period
Weapon Types Expended across Time Periods
Target Types Destroyed across Time Periods

There is a fundamental difference between the "by time period" and the "across time period" worksheets. For the former the graphed values are the percentages for each time period. Thus, the graphed values sum to 100 percent. In the latter case, the graphed values are the percentages over all time periods, and may exceed 100 percent due to target regeneration.

A special HEAVY ATTACK report (DWUNCL) was created to export data to QuikDraw. This report contains the data necessary to generate the graphs, plus some specific syntactic semaphores for the Quattro Pro parsing function. The parsing semaphores allow Quattro Pro to identify only the necessary columns from a report table, significantly reducing the amount of data kept in the worksheets.

Figures 4-5 and 4-6, Attack Missions Flown and Weapons Expended, are examples of "by time period" graphs. With these graphs the analyst and the theater team can instantly see how the aircraft were allocated, or weapons expended in time period one. This analysis takes minutes rather than the tens of minutes or hours required to analyze the current reports. In addition this analysis is more thorough.

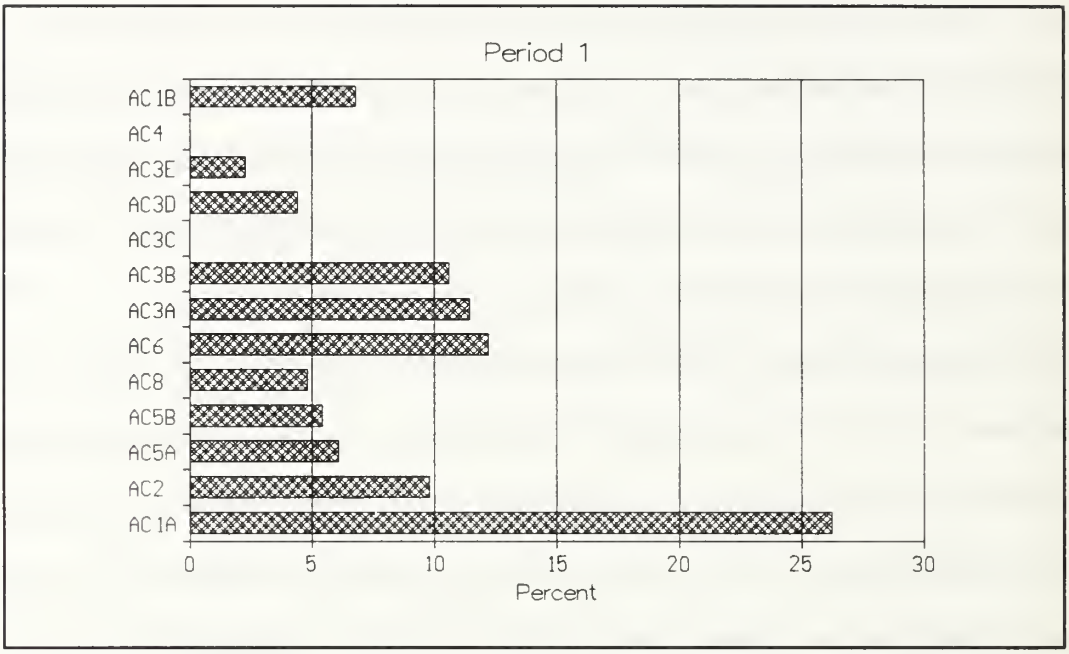

Figure 4-5. QuikDraw current run graph of Aircraft Attack Missions Flown by Time Period for time period 1 using the unclassified data set. Percentages sum to 100.

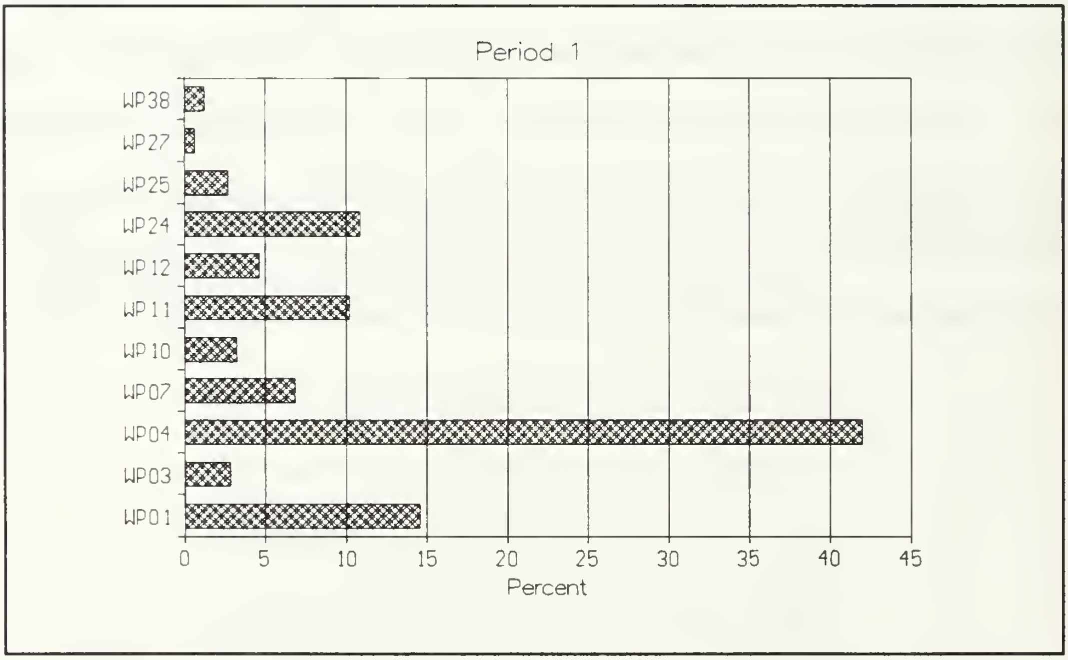

Figure 4-6. QuikDraw current run graph of Weapons Expended By Time Period for time period 1 using the unclassified data set. Percentages sum to 100.

Another feature of QuikDraw is the ability to view multiple runs. Figure 4-7 is an example of a multiple run graph, showing how the expenditure of weapons is affected by removing an aircraft from the data set. To produce this graph, HEAVY

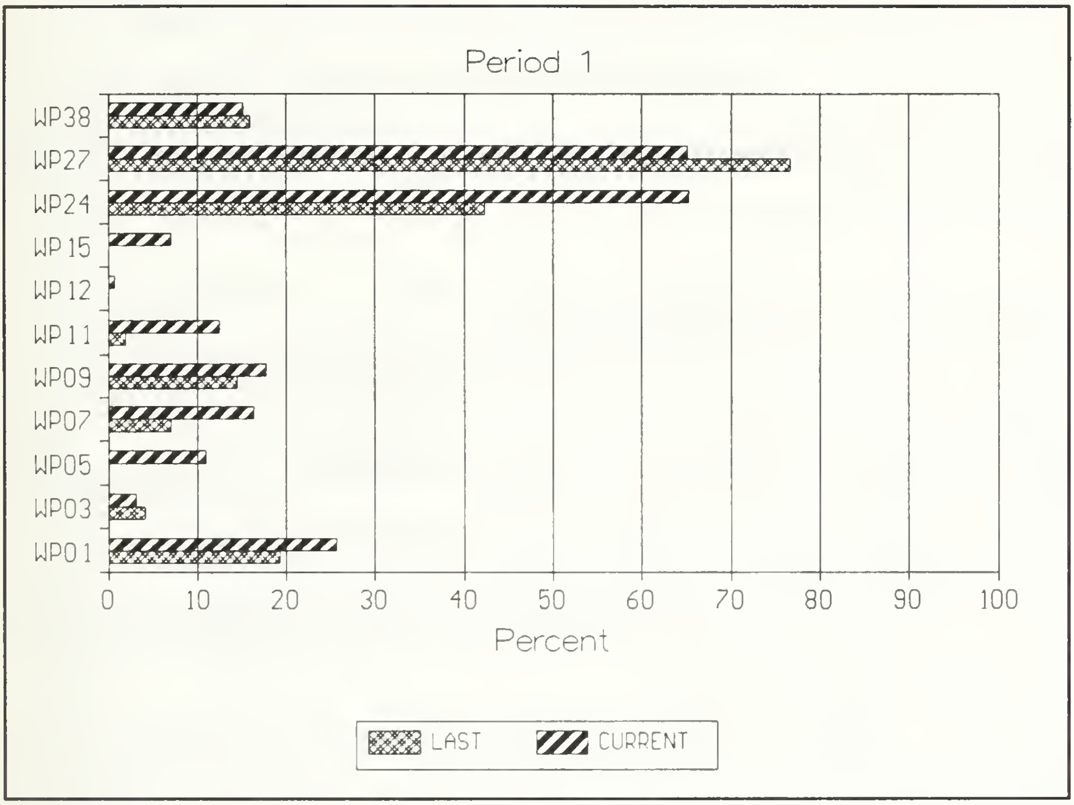

Figure 4-7. QuikDraw multiple run graph of Weapons Expended Across Time Periods for time period 1 using the unclassified data set.

ATTACK first executed with thirteen aircraft types in the data set. The weapons expended by those aircraft are represented by light-shaded, double cross-hatch bars labeled Last (run). Aircraft AC6, having flown about thirteen percent of the missions in the first run, was removed from the data set and the model re-run. The weapon types expended by the remaining twelve aircraft are represented by the heavy-hashed bars labeled Current (run). The analyst/theater teams are then able to analyze how removing an aircraft from HEAVY ATTACK affect the expenditure of weapons. With

QuikDraw the analysis takes minutes, rather than the hours analyzing the HEAVY ATTACK reports by hand.

Finally, QuikDraw allows the analyst/theater team to view cumulative results over "the course of the war" (all seven time periods). An example is Figure 4-8 showing how the target data base was destroyed during the "war". Here five of 38 targets had higher than 100 percent destuction because of HEAVY ATTACK's target regeneration feature.

B. TESTING AND IMPLEMENTATION

QuikDraw was tested using three different subsets from an unclassified data set provided by the United States Air Force Combat Forces Division. The tests generated high confidence that Data Entry worksheets provide HEAVY ATTACK with relatively quick-entry and error-free input. The tests also generated all three graph types for the four Output Listing worksheets.

QuikDraw consists of 12 files, 24 graphs, nearly 178,000 spreadsheet cells, and 1,100 lines of Quattro Pro macro coding using nearly 1,900 macro instructions. The FORTRAN code to convert the QuikDraw Data Entry worksheets into the HEAVY ATTACK input files consists of 581 lines. QuikDraw is available from the author or Professor Bradley.

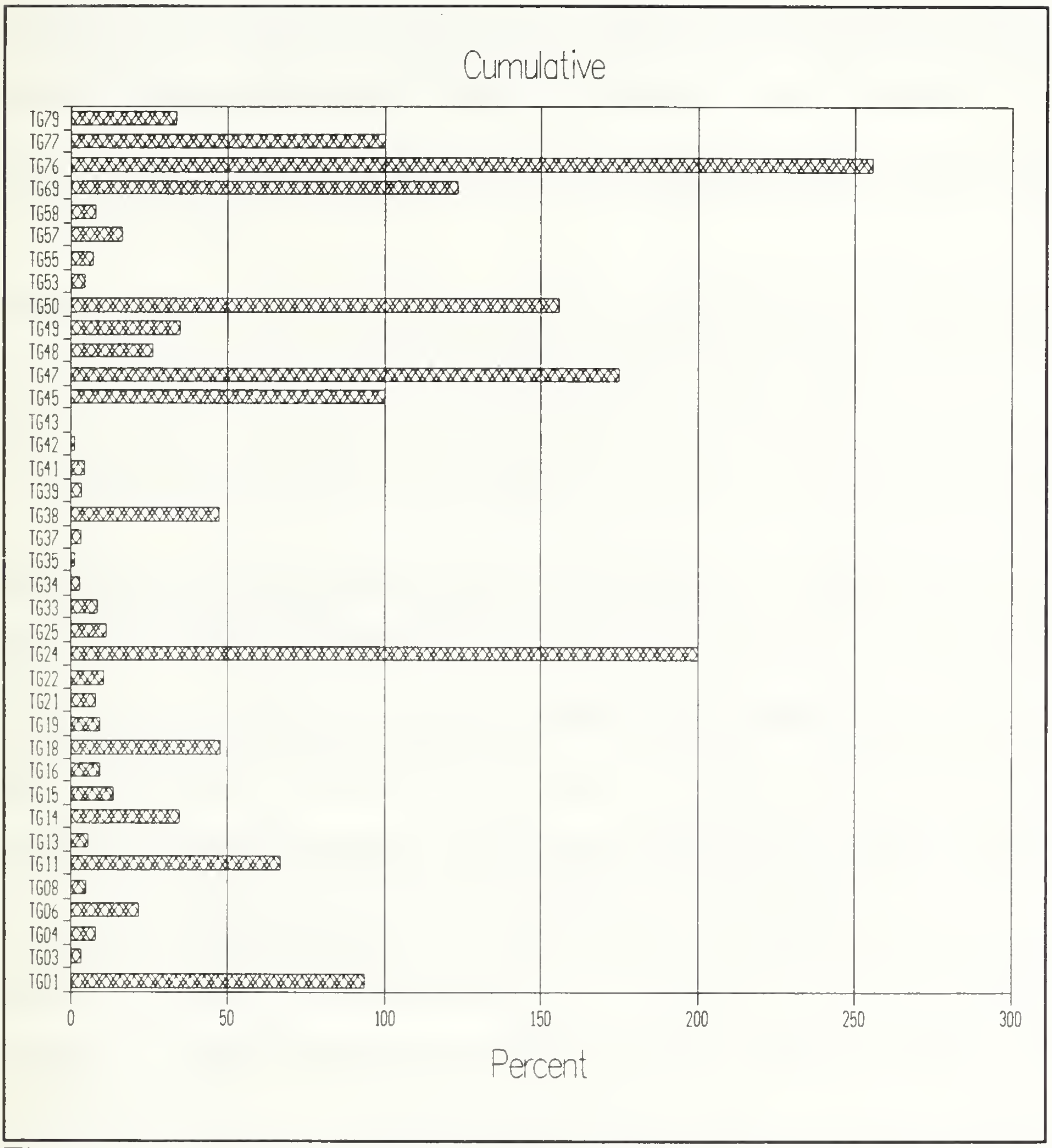

Figure 4-8. QuikDraw cumulative graph of Targets Destroyed Across Time Periods for time periods 1—7 using the unclassified data set. Total percentages may exceed 100% of available target types due to regeneration.

V. CONCLUSION

HEAVY ATTACK is an important operations research model. It has been used for over 20 years and may continue to be used in the foreseeable future. The improvements in analyzing this model offer significant savings in man-hours and money.

HEAVY ATTACK is just one example of using a spreadsheet as a tool to analyze output. The approach developed here to (1) analyze a decision-making process, (2) design analysis tools, and (3) demonstrate them, can be applied to other large-scale optimization models.

This thesis designed and implemented a state-of-the-art output analysis system that demonstrates analysis choke points can be reduced or eliminated. The current cumbersome, time-consuming data input and quality assurance process is replaced by QuikDraw which does the same work in significantly less time, reduces errors in the input files, and minimizes the time spent analyzing hundreds of sheets of output through the use of graphics. In total this improves the quality of analysis.

A preliminary version of QuikDraw was demonstrated to the United States Air Force Combat Forces Division in Washington D.C. in December 1991. As a result of the demonstration, they intend to incorporate QuikDraw into the next generation NCAA process, which will be based on a 486 personal computer.

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